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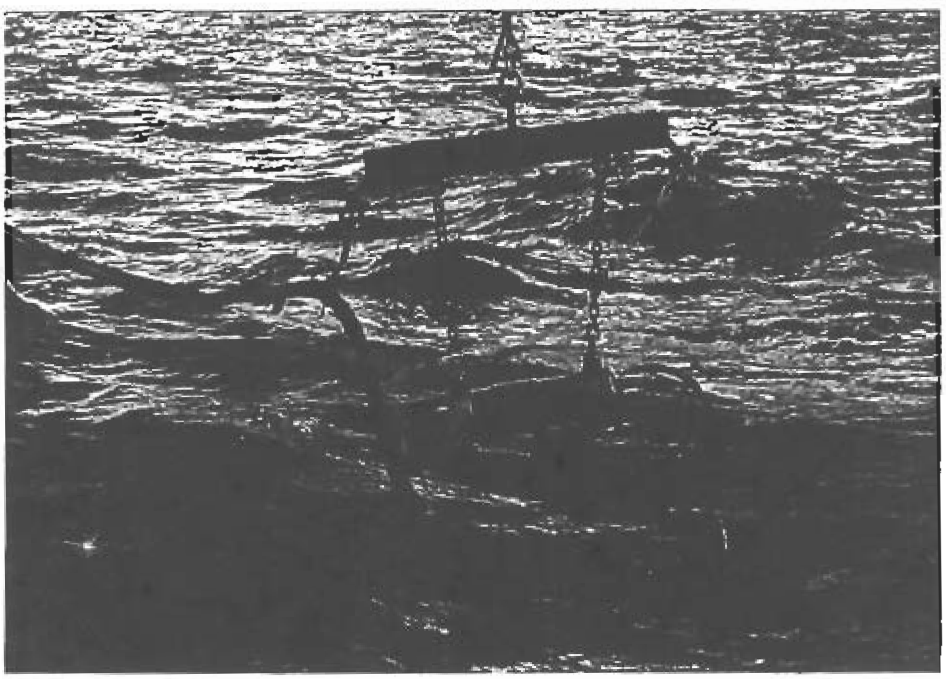
R/V Cape Hatteras Cruise CH 18-95
Legs 1 and 2

Seismic Studies on the Blake Ridge Gas Hydrates

Cruise Report



Beaufort - Beaufort (N.C.)

Leg 1: 15 Nov. - 21 Nov. 1995

Leg 2: 26 Nov. - 1 Dec. 1995

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Contents

1. Scientific Party

Leg 1: 15 Nov. - 20 Nov. 1995

Deborah R. Hutchinson	U. S. Geological Survey	Chief Scientist
John Evans	U.S. Geological Survey	Technician
Judith Gunther	Popular Science	Observer/Journalist
Robert Hammond	Ch. 4 Independent News	Observer/Journalist
Tori Hoehler	Univ. North Carolina, Chapel Hill	Scientist/student
Daniel Lizarralde	Woods Hole Oceanographic Inst.	Scientist/student
Thomas F. O'Brien	U.S. Geological Survey	Engineer
Ingo Pecher	Woods Hole Oceanographic Inst.	Scientist
Julian Rush	Ch. 4 Independent News	Observer/Journalist
Andrew Veitch	Ch. 4 Independent News	Observer/Journalist
Harold Williams	U.S. Geological Survey	Mechanical Engineer

Leg 2: 26 Nov. - 1 Dec. 1995

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Rebecca Drury	U.S. Geological Survey	Technician
John Evans	U.S. Geological Survey	Technician
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Harold Williams	U.S. Geological Survey	Mechanical Engineer

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2. Cruise Overview

Scientific Background

R/V/ Cape Hatteras cruise CH 18-95 utilized seismic methods to study of the gas hydrate deposits of the Blake Ridge region, offshore South Carolina, in conjunction with drilling of Site 994 and 995 of the Ocean Drilling Program (ODP) Leg 164. Gas hydrates are a solid structure in which ice forms a cage around a guest gas molecule (usually methane). Natural hydrates are stable in two environments: permafrost regions because of low temperatures (continental hydrates) and deep sea sediments because of high pressure (oceanic hydrates). The amount of oceanic hydrates is believed to exceed that of continental hydrates by about two orders of magnitude (e.g. Sloan, 1990).

Scientific interest in natural gas hydrates has increased during the last decade, and this cruise, together with ODP drilling, is part of this growing interest. The significance of natural gas hydrates is largely due to the huge volume of methane which is assumed to be stored in hydrates. The amount of carbon present in hydrates worldwide exceeds that from fossil fuels by a factor of two (Kvenvolden, 1988). Consequently, hydrates represent a huge potential energy reservoir. Development of the Siberian Messoyakha continental gas hydrate proves the technical feasibility of a long-term methane production from hydrates (e.g. Makogon, 1988).

A second reason hydrate is significant is their effect on seafloor stability. The base of the gas hydrate zone may represent a zone of weakness within the sediment column because hydrates, which act as bonding agents within the hydrate bearing layer, may inhibit normal sediment consolidation and cementation. Also, free gas may be accumulated at the base of the hydrate stability zone leading to excess pore pressure. Along the southeastern U.S. coast, locations of slope failure apparently concentrate slightly seaward of the line at which the hydrate stability zone intercepts the seafloor, although the gentle dip of the seafloor of $< 6°$ at these depths would indicate a relatively stable slope (Booth et al., 1994), an observation which clearly supports the hypothesis of hydrates being potentially involved in marine slope failure.

A final reason for studying gas hydrates is their potential link to climate changes. The amount of methane stored in hydrates is believed to be ~ 3000 times the amount currently present in the atmosphere (Kvenvolden, 1993). Since methane is a greenhouse gas, release of hydrates would have climatological implications. This process appears to be very complex, involving several factors which are difficult to constrain, in particular how much methane released at the seafloor may propagate through the water column without being dissolved and finally reach the atmosphere (e.g. Kvenvolden, 1994).

Prominent seismic reflectors, referred to as bottom simulating reflectors (BSRs) or gas hydrate reflectors, are often associated with the base of the gas hydrate stability zone. They are caused by a negative seismic impedance contrast which is mostly assumed to be due to the presence of free gas trapped beneath low-permeable hydrated sediments (e.g. White, 1977, Singh et al., 1993, MacKay et al., 1994). BSR occurrence in reflection seismic data has so far been the most important marker for the presence of hydrates in marine sediments. However, not all hydrates which have been recovered during drilling were located above BSRs.

During the last few years, a number of innovative techniques have been developed and applied to identify and possibly quantify the occurrence of oceanic gas hydrates: e.g. amplitude reduction (Dillon et al., 1994), large-aperture reflection and refraction (e.g. Katzman et al., 1994), and vertical seismic profiling (e.g. MacKay et al., 1994). Common to these approaches is the sensitivity of both compressional (P-) and shear (S-) wave velocity to the presence of gas hydrate: rigid (higher velocity) hydrate is assumed to replace part of the (lower-velocity) pore waters during hydrate formation.

This report describes cruise CH 18-95, in which gas hydrates were studied on the Blake Ridge using single-channel seismic (SCS) reflection profiling, large-aperture ocean bottom seismometer (OBS) lines and walkaway vertical seismic profiles (VSPs). The OBS data (in which seismometers are located on the seafloor) are well suited to resolve small-scale velocity variations in hydrate layers (e.g. Katzman et al., 1994, Korenaga et al., 1995, Spence et al., 1995). The walkaway VSP data (in which seismometers are clamped within a borehole at various depths) enhance the seismic ray coverage. Both of these large-aperture data sets take advantage of possible P- to S-wave conversion at the seafloor and the BSR. S-wave velocity may be more sensitive than P-wave velocity to the presence of small amounts of hydrate in sediments if hydrate acts to bond sedimentary grains (e.g. Lee et al., 1993).

Cruise CH 18-95 occurred in conjunction with drilling of ODP Leg 164, Holes 994 and 995 on the Blake Ridge in order to collect zero-offset and walkaway VSPs during drilling and to conduct isotopic experiments that could not be conducted on the drill ship because of contamination concerns. A key objective of this two-ship work is to relate physical properties of the sediments (e.g. seismic velocity) with hydrate concentration. The results of these "calibration" analyses, when combined with drilling properties and ongoing laboratory measurements in the U.S. Geological Survey Gas Hydrate Laboratory (Winters et al., 1995), will enable researchers to understand how small-scale fluctuations observed in seismic data constrain hydrate distribution and concentration. This may ultimately lead to new techniques and approaches for mapping hydrate occurrence in marine sediments world wide.

Experimental Overview

Cruise CH 18-95 took place in two legs, with each leg timed to coincide with ODP drilling of holes 994 and 995 on the Blake Ridge. The seismic experiments were designed to provide the maximum flexibility in conducting the two-ship walkaway VSP experiments; i.e., *R/V Cape Hatteras* could conduct single-channel or OBS profiling in the vicinity of the drill hole while "standing by" for the beginning of VSP operations. The *Cape Hatteras* also provided transportation for personnel transfers and supplies to and from the *Resolution* during each leg.

The following studies were conducted during **Leg 1** of the cruise:

1) A walkaway VSP experiment over Hole 994D in which *R/V Cape Hatteras* provided the sound source for a three-component seismometer set in the drill hole from *R/V JOIDES Resolution*, a geometry required to acquire walkaway VSPs.

2) Collection of single channel seismic (SCS) profiles to complement other geophysical data associated with ODP Leg 164 drilling.

3) Isotope analyses on samples collected by *R/V JOIDES Resolution*.

The following seismic operations were conducted during **Leg 2**:

1) Two OBS experiments, one in a location in which little hydrate is thought to be present and one over ODP Site 994D.

2) A walkaway VSP experiment over Hole 995B.

3) The acquisition of additional SCS profiles of the region to complete the series of lines begun on the first leg.

These operations were successfully carried out.

Seismic Source

A generator/injector (GI) gun (® Seismic Systems Inc.) was used as the seismic source during the entire cruise. The GI gun consists of two independent airgun chambers configured for a size of 1.7 l (105 in^3). The first chamber (generator) produces the primary pulse. The second chamber is fired with a slight delay to suppress the bubble created by the first chamber. A gun phone attached to the GI gun provides information to monitor the nearfield and to determine the optimum delay between the trigger signals for each chamber. Fig. 1 displays the principal operation of a GI gun.

Delay times were adjusted according to the firing pressure and gun depth. The gun depth was maintained by tethering the gun assembly on three Norwegian buoys. Tests to optimize tuning of the gun using signals from both the streamer and the gun phone were conducted on the first leg. Delays were varied from 30 to 53 ms. A 45 ms delay gave optimal bubble-pulse reduction at 210 bar (3000 psi) pressure and 5 m depth of the gun. No similar tests were conducted on Leg 2 since we used the same source configuration.

Pressure was generated using two compressors which worked almost without problems during the whole cruise. Airgun pressure usually was between 140 and 210 bar (2000 - 3000 psi). The gun was towed approximately 45 m behind the stern of the ship and was boomed out on the starboard side. It was generally fired every 15 s.

Navigation

Three independent systems were used to record navigation: (1) The USGS *Rockwell* GPS device was able to decode the military GPS fixes (P-code fixes). P-code fixes were recorded directly to a PC using the program *debbie5* that logged latitude, longitude, and time every 5 seconds. These navigation files were downloaded to floppy disk at the end of each VSP line. The P-code navigation data are expected to yield positions to an accuracy of ~10m. (2) The shipboard *Ashtech* GPS (on the bridge) decoded the Coast Guard transmitted differential corrections, when these signals were available, which appeared to be ~50% of the time. We were at the seaward limit of the transmitting beacons' range. The differentially corrected signals have a potential position accuracy of ~1m. (3) The WHOI *Ashtech* GPS fixes were stored internally of the GPS unit and were downloaded to floppy disk at the end of each VSP line using the *Ashtech hose* program. A similar procedure was carried out aboard the *Resolution* with the aim of performing differential post processing to two walkaway VSP data sets and producing ship-to-ship relative range information with accuracies on the order of ~10 cm. It was noticed that our *Ashtech* unit was not tracking satellites as effectively as a second *Ashtech* unit which was on board (being used to power the P-code receivers antenna). Efforts to explain this discrepancy were unsuccessful. Antenna location, antenna type, and GPS power supply were eliminated as possible causes.

Single-Channel Seismic Lines

Two-channel seismic lines were acquired to augment the already existing site-survey data for ODP Leg 164 as well as during the shooting of the OBS lines and during one of the transits of each walkaway VSP line. We refer to those data as single-channel seismic (SCS) lines, because pre-stack information will not be used for further interpretation due to the small distance between both channels.

The *Teledyne* two-channel streamer consists of two 50 m-long active sections separated by a 25 m-long dead section towed approximately 94 m behind the stern of the *Hatteras*. The streamer signal was passed through a bandpass antialiasing filter with 3 dB points at 5 and 100 Hz with 48 dB/octave rolloff at the low end and 128 dB/octave rolloff at the high end. This signal was then sent to the *a2d* acquisition software running on the shipboard SUN workstation and sampled at a 2 ms rate. The output SEG-Y files of the *a2d* software required postprocessing via the *processSegy* program of T. O'Brien to convert the output to voltages. We note that the final gain settings of the two channels do not appear to be perfectly balanced and should be regained prior to stacking of the channels. Shot numbers originally increased successively without resetting them at the start of each line. After splitting the records into individual lines, we changed shot numbers to start with 1 at the beginning of each line. Further organization of the SEG-Y data recorded on the two legs is discussed further below in the section about data management.

VSP Operations

VSP operations were carried out in conjunction with the *Resolution* at Sites 994D (31°47.131'N, 75°32.726'W) and 995B (31°48.244'N, 75°31.360'W). Our operations involved: (1) firing of the GI gun at ~15 s intervals (randomized about a 0.4 s mean during the first 5 station depths of Leg 2, (2) recording of shot-time instants using the SAIL system and (3) recording of navigation data in the form of 5 s fixes from a P-code GPS receiver, 20 s fixes from the *Ashtech* GPS receiver, and 1 minute fixes from the ship board GPS.

Shot instant times were recorded using the *shot_log* program run on a PC. The program was terminated at the end of each VSP line and the shot time files downloaded to floppy disk. A rising-edge pulse was sent to the sail clock of the shot-logging system directly from the trigger which powered the solenoids to fire the gun. The delay time between this trigger pulse and the actual firing of the gun was measured to be 0.0093 s during both legs. This delay, when added to the GPS/Sail-clock offset time of 0.0007 s, results in a net delay of 0.0100 s, between the logged shot times and the actual shot instant time.

Originally, it was planned to intermingle zero-offset and walkaway VSP measurements, so that the seismometer tool was moved through the hole only once. Spacing of the walkaway stations was planned to be 80 m with zero-offset VSP stations located every 8 m.

During the first Leg, walkaway operations were only carried out at two receiver depths, 482 and 645 mbsf. Furthermore, at the 482 mbsf only the southwestern half-spread of the airgun profile was shot. This was mainly due to expansion within the hole and to problems with unclamping the VSP tool within the borehole. The shooting itself went smoothly without incident. The shot randomizer was not used however, since the *shot_log* program appeared to be unstable during testing and recovery of shot times should the program fail would be easier if the randomizer was switched off. The first experiment (495 mbsf) was conducted on 17 Nov. (JD 321) 15:31 - 16:36 GMT. After that, the *Resolution* reported problems with one of the clamping arms of the VSP tool, so that the tool had to be hauled in for repairs. The hole was then reconditioned. We therefore acquired SCS lines before resuming shooting the second VSP line (645 mbsf) on 18 Nov. (JD 322) from 19:32 - 21:24 GMT. When it turned out that again one of the clamping arms broke while trying to unclamp the tool, the *Resolution* decided to abandon the walkaway VSP experiment in this hole and to try instead to resolve the problems with the tool before starting the next VSP experiment at Site 995. Because only two depths of a planned set of eight walkaway stations were completed successfully, we decided to conduct an OBS line at this site to provide more ray path coverage.

During the second leg, the operations in the drillhole went without any significant problems. This had been achieved by several improvements: 1) the decision to conduct the walkaway experiment independent of the zero-offset VSP experiment, 2) the immediate employment of the "side-entry sub", with a strategy of conducting one walkaway per each section of drill pipe removed above the side-entry sub, yielding a station spacing of 72 meters depth, and 3) adjustments to the operation of the VSP tool's clamping arm. Walkaway experiments were conducted at the following depths below seafloor: 680, 608, 536, 464, 392, 320, 248, and 276 mbsf.

The experiment occurred between 29 Nov. (JD 333) 18:48 and 30 Nov. (JD 334) 17:08 GMT in 2- to 3.5-m seas with the *Hatteras* transiting perpendicular to the swell. The shot-time logging system failed on several occasions. The first failure was from 01:07 to 01:45 of V995B03. When it was noticed that the *shot_log* times were not updating, the PC was rebooted and normal operation resumed. The problem reoccurred ~1 hour into the shooting of V995B06. This occurrence coincided with a substantial roughening of the sea state causing rolls up to 30° as winds increased to 25 kts. An effort was made at this point to analyze the problem. The *shot_log* program display was blinking as it received triggers, but the shot times were not updating and an error message - unreadable - was also blinking onto the screen. The PC was rebooted twice to resume normal operation, but it was noticed that the shot logger was occasionally updating at 1s intervals.

Using an oscilloscope, we verified that triggers were being sent properly from the randomizer. Flashing lights on the blue control linking the SAIL logger with the PC box also seemed to suggest that the sail loop was being activated in the proper manner. The randomizer was turned off at this point to aid in recovery of subsequent shot times.

Attempts to port *Procom* and *shot_log* to a lap top were not successful. The system failed again during line 7 from 12:25-12:42 and 13:01-13:06, and during line 8 for the final 10 minutes of shooting.

We suspect that the extreme motion of the ship may have played a role in the system failure. We note also that during normal operation it was not possible to address the floppy drive B: immediately after ending the *shot_log* program without first rebooting the PC and that upon a soft reboot (ctrl-alt-del) we invariably encountered a "keyboard failure" error message.

An additional failure occurred at the start of V995B05 due to operator error. The GPS offset was checked at the end of V995B04 and the sail clock was left in the "arm" position for ~20 minutes into the shooting of V995B05. A copy of the manual for the shot logging system is available at the U.S. Geological Survey Data Library (Woods Hole).

OBS Deployments

Two deployments of two USGS OBSs were performed on the second leg. The first OBS deployment was ~100 km south of the ODP sites in an area with no strong BSR, weak blanking and ~3650 m water depth (Table 1). This site was chosen to provide a control wide-angle dataset for comparison with data from the hydrate-bearing sediments of the Blake Ridge. The second deployment was located over the 994D drill site in ~2800 m of water and was designed to complement the incomplete VSP experiment acquired on the previous leg. The geometry of these experiments (Figures 5 and 6) incorporated perpendicular, ~30-km-long, strike and dip lines with the OBSs located in the center along the strike lines and separated by 2.5 and 2.0 km in the first and second deployments, respectively.

Both experiments were conducted in fair weather without significant incident. The second deployment was shot in two stages, with data being acquired only between the east-west and north-south waypoints. The instruments were deployed and the east-west line shot. The *Hatteras* then sailed from the area in an effort to rendezvous with the *R/V Susan Hudson* and transfer Greg Lovelace to the Hudson. This attempt was aborted due to weather too severe for the *Hudson*. We then returned, completed the north-south portion of the experiment and recovered the instruments. The data appear to be of very high quality (fig. 10).

Underway Operations and Data Management

Matlab and GMT were installed on the SGI workstation while underway in order to process and plot navigation data and to perform the following tasks: calculating ranges for the VSP walkaway and OBS lines; plotting ship tracks and organizing SCS data into an orderly line-number system; placing latitude and longitude of shots into the SEG-Y headers of the SCS data; and generating maps for the cruise report. These tasks were performed successfully. We failed on each instance, however, to electronically transmit shot times with calculated ranges: the multiple-file format of the shot-time/range data was not transmitted properly via the COMSAT e-mail system of the *Hatteras*. We managed, however, to manually provide *shot_log* files for the walkaway VSP experiment at Site 994D during personnel transfer to the *Resolution*. Following the VSP operations at 995B, the quick rendezvous with the *Resolution* did not permit adequate time to process the navigation data for all walkaway lines.

The GMT mapping software (Wessel and Smith, 1991) was used to generate shiptrack maps of the acquired seismic lines. These maps were based on the 5 s P-code fixes and shot times which were recorded to the nearest second in the SEG-Y headers of the SCS data. The shiptrack maps were used to organize the SEG-Y data into files corresponding to numbered lines (Table 4). The shot times extracted from the SEG-Y headers were linearly interpolated onto the gun positions determined at the 5 s P-code fixes and placed into the SEG-Y headers in 2-byte positions 70-75 as degree, whole minute, and decimal portion of minute.

Media Coverage

The growing interest in hydrate research by academic and government scientists has caught the attention of the popular media as well. Because the *Cape Hatteras* legs were short and berthing was available, they were a convenient platform for media personnel to observe operations on the *Hatteras* and transfer to the *Resolution*.

Five media persons participated in the two legs: four guests were aboard for the first leg - a contributing editor from *Popular Science* (Judith Gunther) and three representatives of *Independent Television News* (ITN) in Great Britain (Julian Rush - science producer, Andrew Veitch - science reporter, and Robert Hammond - camera man). On the second leg, a director of the research news service of the University of North Carolina (David Williamson) was aboard. Each of these five observers spent at least a day aboard the *Resolution* conducting interviews, taking pictures, and filming.

The documentary video produced by the ITN team aired on Friday, 24 November 1995, in Great Britain, and was subsequently carried to *Cable Network News* (CNN) in the U.S. and internationally. Copies of the video are archived at the Data Library, U.S. Geological Survey, Woods Hole. As of April 1996, the article for *Popular Science* has not yet been published.

3. Narrative/Log Summary

Leg 1: 15 Nov. - 20 Nov. 1995

15 Nov. 1995, JD 319
13:23: Depart Duke Marine Laboratory at Beaufort, N.C.

16 Nov. 1995, JD 320
11:00: Transfer of media persons, Tori Hoehler, and equipment to Resolution.
14:00: Calibration tests with GI gun, using 105 in^3 chambers for both the generator and the injector pulses. A 40 ms delay between both pulses was chosen in order to obtain an optimum source signature.
22:00: Picking up media persons from the Resolution. Tori Hoehler will be transferred later.

The Resolution reports problems with drill hole 994C, which therefore will be abandoned. A new hole will be drilled as Site 994D to perform logging and the VSP experiment.

Weather: Seas moderate with occasional white caps.

17 Nov. 1995, JD 321
00:10: Begin SCS Line 1. Gun pressure was about 140 bar (2000 psi). See table 5 for navigation. This line connects all drill sites at Blake Outer Ridge.
01:19: GI gun was shut off due to problems with the supply cables.
01:39: GI gun resumed shooting
04:41: End of SCS Line 1.
04:57: Begin SCS Line 2.
05:45: The Resolution won't be ready for the VSP experiment before at least 12:30.
06:25: End SCS Line 2.
06:43: Begin SCS :Line 3.
08:13: End SCS :Line 3.
08:43: Begin SCS Line 4.
10:04: End SCS Line 4.
12:00: Transfer of Tori Hoehler together with some equipment from the Resolution.
15:31: Begin shooting the first walk-away VSP line V994D01. Due to problems with the hole, only half of the originally planned line was shot (the southwestern branch, fig. 9). The geophone depth was 493 mbsf.
16:36 End Line V994D01.

The bore hole must be reconditioned before further measurements can be performed. Therefore, the acquisition of SCS data was resumed.

19:43: Begin SCS Line 5.
22:55: End SCS Line 5.

Weather: Seas moderate, winds 10-20 knots.

18 Nov. 1995, JD 322
00:30: Begin SCS line 6. Data lost because of bug in the data acquisition program *a2d*.

Further delays are anticipated for the second VSP line due to problems with the power supply on the *Resolution*.

01:43 End SCS Line 6.
06:31 Begin SCS Line 7.
08:56 End SCS Line 7/Begin SCS Line 8. In order to obtain higher spatial resolution, profiling was done with 1.5-2.0 knts instead of 4-5 knts as for most other lines.
10:19 End SCS Line 8.
10:43 Begin SCS line 9.
11:33 Profiling was interrupted, the guns turned of and streamer hauled in because the *Resolution* say that they will be ready in 20 minutes.
12:40 Another damage at the drill ship, anticipating at least 6 hours delay.
13:08 Begin SCS Line 10. This line was again acquired at 1.5-2 knts. After having repaired a valve at the compressor, gun pressure was raised from 140 to 210 bars (2000 to 3000 psi).
14:27 End SCS Line 10, begin Line 11. Line 11 acquired at 4.5 knts.
14:49 End SCS Line 11, begin SCS Line 12. This is the final part of Line 9, however, shot into the opposite direction (i.e., the position at 15:35 is about the same as that at 11:33).
15:35 End SCS Line 12.
17:18 Begin SCS Line 14.
18:14 End SCS Line 14, begin SCS Line 15.
18:30 End SCS Line 15

Next walkaway VSP experiment should start in 20-30 mins. Thus, we are heading towards starting point for the walk-away VSP.

19:30 Second VSP line V994D02 with receivers at 650 mbsf. This time, the whole spread over the bore hole was shot.
21:24 End V994D02.

Weather: Seas calm, winds 10-20 knts.

19 Nov. 1995, JD 323

00:00: The instruments in the hole obviously were damaged while trying to pull them up to the next position. Therefore, SCS profiling was resumed.
01:00 Begin SCS Line 16.
03:13 End SCS Line 16, begin SCS Line 17.
06:54 End SCS Line 17, begin SCS Line 18.
10:59 Begin SCS Line 19.
11:20 Terminating SCS Line 19 because acquisition of the next VSP line should be started soon.
15:00 *Resolution* reports that the tool was damaged in the hole again. Therefore, the they decided to terminate the VSP experiment at Site 944D and to try to fix the problems with the tool for a possible VSP experiment at Site BRH-6. The *Cape Hatteras* steamed further north to acquire seismic data from the Blake Diapir area.
22:29 Begin SCS Line 20.
00:00 Passing Blake Diapir.

Weather: Seas calm, winds 10-20 knts.

20 Nov. 1995, JD 324

01:29 Begin SCS Line 21. Due to a leak in the GI gun air supply, the pressure was lowered from 210 to 150 bar (3000 to 2200 psi).

03:29 End SCS Line 21, begin SCS Line 22.
03:29 End SCS Line 22, begin SCS Line 23.
05:00 Passing diapir again.
09:46 SCS Line 24.
12:20 End SCS Line 24. Hauling in gear, heading for Beaufort.
22:00 Arriving at dock.

Weather: Seas calm, winds 10-20 knts.

Leg 2: 26 Nov. - 1 Dec. 1995

26 Nov. 1995, JD 330
16:00 Left dock under fair skies for immediate rendezvous with the *Resolution* to transfers the repaired VSP part, Dave Williams, and several ODP boxes to the drill ship and receive an update on drilling operations at Site 995.

27 Nov. 1995, JD 331
12:00 Rendezvous with the drill ship, make transfer. VSP operations scheduled to begin Wednesday at noon. Begin transit to first OBS site ~50 nm to the south.
18:10 Deploy OBS A2. Beautiful sunshine, calm wind and seas.
18:24 Deploy OBS A3
20:18 Begin shooting OBS Line 1 pattern.

28 Nov. 1995, JD 332
07:07 Shooting of OBS Line 1 pattern complete. Begin recovery operations.
08:24 OBS A2 released.
09:29 OBS A2 recovered.
09:59 OBS A3 released.
11:09 OBS A3 recovered.

Upon completion of the 1st OBS experiment, we made way for the drill sites with the intention of deploying the OBSs and potentially conducting the 2nd OBS experiment before beginning VSP operations. We were contacted by Quinton Lewis over single-side band and informed of ODP's (shore-based office) desire for us to remove an infirm marine technician, Greg Lovelace, from the *Resolution* and transport him to shore at our earliest convenience. After a second conversation with Quinton we devised a plan wherein we would rendezvous with the *Resolution*, retrieve Lovelace, deploy the OBSs over site 994D, shoot the east-west line, then transit to the offshore limit of the *R/V Susan Hudson* where we would rendezvous with her and transfer Lovelace and, apparently, a shipment of food stores which had arrived in Beaufort for the *Resolution*. VSP operations were schedule to begin at 17:00Z the next day.

16:00 Rendezvous with the *Resolution*, Lovelace on board.
17:14 OBS A3 deployed.
17:30 OBS A2 deployed, begin transit to west end of dip line.
18:44 Begin shooting line OBS 2a.
22:36 End of line OBS 2a.
23:00 Equipment hauled in, begin transit to rendezvous with the *Hudson*.
23:30 Two hours into the *Hudson's* transit her crew decided to abort the plan due to rough seas. We begin transiting back to the OBS Line 2 site to complete the OBS experiment.

29 Nov. 1995, JD 333

01:24 Begin shooting OBS 2b, the strike line in relatively calm seas with 15-20 knt winds and moderate swells.
05:20 End of shooting Line OBS 2b.
06:49 OBS A3 released.
07:58 OBS A3 on board.
08:13 OBS A2 released.
09:15 OBS A2 on board. The SCS gear is immediately deployed.
09:38 Begin SCS Line 25.
11:57 End SCS Line 25, begin SCS Line 26.
12:20 End SCS Line 26.
12:21 Begin SCS Line 27.
13:32 End of SCS Line 27, begin SCS Line 28.
15:10 End of SCS Line 28.

Seas continued to roughing after the recovery of the OBSs. Following a conversation with the *Resolution*, we steamed to the end of VSP Line V995B01 and stood by.

18:48 Begin V995B01
21:24 End V995B01
21:56 Begin V995B02

30 Nov. 1995, JD 334

00:15 End V995B02.
00:46 Begin V995B03.
01:07 Shot logger not working. Failure not notice for 30 minutes.
01:45 PC rebooted, shot logger again operational.
03:00 End V995B03.
03:20 Begin V995B04.
05:31 End V995B04
06:03 Begin V995B05.
08:20 End V995B05.
08:45 Begin V995B06.
10:00 It is noticed that the shot_log program is again not working. Shot time has not updated since ~09:10. Begin efforts to analyze the problem, discontinue shot randomizer.
11:23 End V995B06.
12:22 Begin V995B07.
12:42 Failure of the shot logger again noticed. Failure from 12:25-12:42
13:06 Failure of the shot logger from 13:01-13:06.
13:30 It is noticed that one of the flashing lights of the gun selenoids is remaining on. Only one chamber of the GI gun is firing. The firing lines had become wet on the fantail.
13:53 Gun problem fixed. Both chambers firing again.
14:32 End V995B07.
15:06 Begin V995B08.
17:08 End V995B08.

The *Resolution* radios to tell that they made a miscalculation in the number of pipe sections put down above the side-entry sub and that there will be no line 9. We plan a final rendezvous with *Resolution* to transfer a liquid nitrogen bottle to the Hatteras and diskettes with shot times to the *Resolution*. A brief consideration is given to another attempt to rendezvous with the *Hudson* to bring back out the food stores and a replacement tech for Lovelace. The weather is too severe for this operation, however, and we decide to simply pick up several remaining lines and end the cruise early.

19:19 Begin SCS Line 29.
20:42 End SCS Line 29, begin SCS Line 30. It is noticed at this time that spurious but ordered signals are being recorded by our system. Upon realizing that these were the airgun shots from the zero-offset VSP shooting of the *Resolution*, we contacted them to see if we were interfering with their experiment. It was decided to continue with our shooting, as our source was significantly weaker than theirs, we were in constant motion, and we were heading out of the area.
21:48 End SCS Line 30, begin SCS Line 31.
22:34 End SCS Line 31
23:04 Begin SCS Line 32.

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01:19 End SCS Line 32. Haul in gear, head for Beaufort.
14:00 Arriving at dock.

4. First Results and Comments

Seismic Source

The GI gun worked without failing during the entire operation, which is remarkable considering the overall length of the profiles (ref. also figs. 2-5). Harold Williams performed some maintenance work on the gun between both legs. Problems with the shooting system were limited to a few irregularities with the triggering system and to the failures of the shot logging system during the second walkaway experiment. The latter problem should be addressed before using this system again, because its failure makes evaluation of any data from two-ship seismic experiments as well as OBS data considerably more difficult and very time consuming.

The signature of the GI gun is excellent, which is e.g. clear from figs. 6 and 7. No deconvolution was applied to those data. Tuning however, was made difficult due to the lack of recording a clean far-field output signal. Future operations would probably benefit from the deployment of a single hydrophone at some depth below the ship to monitor the tuning of the gun.

Single Channel Seismic Data

Fig. 6 shows the dip line over the ODP Leg 164 transect at Blake Ridge. It is obvious from these data (as it was from the data used to locate the drill sites), that the BSR weakens considerable between Sites 994 and 995. However, the BSR does not disappear completely. Strong dipping reflections beneath the BSR, which display considerably lower amplitudes once they cross the BSR, may indicate that gas beneath the base of the hydrate stability zone is aligned parallel to sediment bedding, an effect previously observed in high resolution deep-towed data (Wood et al., 1995). The sharp pulse (negative/positive phase) of the signal from the BSR indicates that gun tuning was optimum. Penetration of the seismic data down to more than 0.5 s beneath the BSR demonstrates that this GI gun is an excellent seismic source for this environment, i.e. a few thousand meters of water, a few hundred meters of sediments and the desire to obtain as high a resolution as possible.

This is again demonstrated in fig. 7, which displays a migrated seismic section above the Blake Ridge Diapir. Migration was performed assuming water velocity resulting in a slight undermigration of the data, which is reflected by some remaining diffraction hyperbola at the crest of the diapir. Otherwise, however, diffraction hyperbole collapsed quite well. A clear BSR can be seen northeast of the diapir (right side) at about 3.4 s TWT at shot no. 1500, shallowing as it approaches the diapir. On the southwestern side, the BSR weakens. About 100 shots (ca. 3 km) away from the diapir, the BSR disappears completely as a single reflection and the base of the gas hydrate stability zone can only be inferred from the amplitude decrease of horizons crossing this base. The pull-up of the BSR close to the diapir possibly reflects a rise in heat flux above the diapir. A change of the chemical composition of pore water, however, might also contribute to this effect (salt, e.g., shifts the phase boundary of methane hydrates towards lower temperatures). The Blake Ridge Diapir was drilled as part of ODP Leg 164. Results from drilling should provide an explanation for this pull-up.

OBS Data

The OBS operation went smoothly without any significant problems. This is also reflected in the high quality of the data. Fig. 10 displays the vertical component of the OBS which was located at Site 994D (BRH 4). Apparent noise in some traces around shot no. 400 can be easily eliminated by applying a spike deconvolution, something we already have tested. The strong amplitudes of the refracted wave at high offsets (even visible in the multiple signal) prove that the GI gun is perfectly suited for this type of experiment, during which seismic waves travel relatively long distances through sediments. This observation also demonstrated that the GI gun was a suitable seismic source for the walkaway VSP experiment.

Walkaway VSP Experiment

The principle setup of the walkaway VSP experiment at Site 995B is shown in fig. 11. Assuming that we will be able to recover the data acquired when the shot logging system failed, a 100% data coverage was achieved at this site. Four of the eight receiver stations were placed above the BSR resulting in a high coverage of rays within the layer of hydrated sediments if reflections from the BSR can be identified in the data. This will probably allow a good tomographic reconstruction of P-wave velocity around the drill hole. Ray coverage beneath the BSR depends on whether sufficient energy is reflected at horizons beneath the receiver positions.

Fig. 12 displays a section of the data (approximately 40% of the whole spread) from the deeper receiver position at Site 994D at 649.9 mbsf (well beneath the base of the gas hydrate stability zone). A slight bubble pulse is seen about 0.15 s after the main signal. The otherwise clean record having a high signal to noise ratio demonstrates the suitability of the GI gun for this experiment. Some reflected energy may be present at the left (northeastern) part of this section characterized by a shallower slope than the direct arrivals.

The data from Site 995B are noisier which is not surprising considering the storm we encountered during these measurements. Fig. 13 shows a section of the data gathered at the shallowest receiver position (175.8 mbsf). The BSR can be clearly identified in these data. Fig. 1 displays the whole spread of these data. The source signature is worse than for all the other seismic data, which might also be due to the severe weather conditions. Two strong bubble pulses will make it necessary to deconvolve the data before interpretation. Despite the high noise level, the direct arrival can be traced over almost the entire data set, indicating again the proper choice of the source. No converted shear wave could be identified in the horizontal components so far. This was expected, however, since shear wave energy is probably quite weak and some processing to reduce the high noise level such as coherency filtering will be required before possible shear wave arrivals might become visible.

Despite the noise due to bad weather, the walkaway VSP experimental setup turned out to be well suited for studies in conjunction with ODP drilling. Problems with the VSP tool in the borehole apparently had been resolved perfectly before drilling of Hole 995B. *R/V JOIDES Resolution* reports will certainly comment in detail on how to address such problems for future drilling. At the shooting ship, our only suggestion for improving the experiment, apart from securing adequate shot logging, would be to try to record the far field of the GI gun to enhance tuning as well as for post-cruise processing. Ideally, this could be done by both towing a hydrophone at some distance beneath the gun to record the near-vertical signature and by recording the signal at the drill ship to obtain the near-horizontal GI gun signal.

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Tables

Table 1. OBS Deployments 1 and 2: deployment, recovery and waypoint positions.

Deployment		Deployed Position		Recovered Position	
1	OBS A2	30.9382°N	75.7209°W	30.9374°N	75.7326°W
	OBS A3	30.9436	75.6944	30.9412	75.7070
	Waypoints:				
	East	30.9737°N	75.5478°W		
	West	30.9087	75.8675		
	North	31.0631	75.7291		
	South	30.8178	75.6596		
2	OBS A2	31.7780°N	75.5647°W	31.7826°N	75.5620°W
	OBS A3	31.7855	75.5454	31.7900	75.5424
	Waypoints:				
	East	31.8379	75.4107		
	West	31.7332	75.6803		
	North	31.9001	75.6070		
	South	31.6709	75.4838		

Table 2. Logged GPS/Sail clock offsets for CH18-95.

Julian day	Time	GPS/Sail Offset
321	13:40	0.000715
321	16:36	0.000715
322	21:38	0.000722
330	22:07	0.000685
331	16:08	0.000743
332	03:45	0.000751
332	04:30	0.000748
332	06:45	0.000757
332	18:27	0.000754
333	02:30	0.000767
333	05:00	0.000770
334	00:40	0.000703
334	03:00	0.000707
334	05:55	0.000707
334	12:05	0.000707
334	16:45	0.000692
335	15:50	0.000698

Table 3: Receiver depths of walkaway VSP experiment in ODP Leg 164 Hole 994D.

Coordinates of bore hole: 31° 47.131' N, 75° 32.726' W
Depth of seafloor: 2810.1 m below rig floor (mbrf)

line	depth (mbrf)	depth (mbsf)	begin (1)	end (1)	Rem.
V994D01	3292	481.9	321 15:31	321 16:36	(2)
V994D02	3460	649.9	322 19:32	322 21:24	(3)

(1) Julian Day and Greenwich Meantime
(2) only southwestern halfspread
(3) slacking a few meters

Table 4: Receiver depths of walkaway VSP experiment in ODP Leg 164 Hole 995B.

Coordinates of bore hole: 31° 48.244' N, 75° 31.360' W
Depth of seafloor: 2788.2 m below rig floor (mbrf)
Approximate depth of BSR: 440 m below sea floor (mbsf).

line	depth (mbrf)	depth (mbsf)	begin (1)	end (1)	Rem.
V995B01	3468	679.8	333 18:48	333 21:24	
V995B02	3396	607.8	333 21:56	334 00:15	
V995B03	3324	535.8	334 00:46	334 03:00	(2)
V995B04	3252	463.8	334 03:23	334 05:31	(2)
V995B05	3180	391.8	334 06:03	334 08:20	(2)
V995B06	3108	319.8	334 09:15	334 11:23	(2)
V995B07	3036	247.8	334 12:24	334 14:32	(2)
V995B08	2964	175.8	334 15:06	334 17:08	(2)

(1) Julian Day and Greenwich Mean Time.
(2) Slacking a few meters.
Refer logs from *R/V JOIDES Resolution* for further details.

Table 5. SCS lines, names of original records.

Line #	SEG-Y File Name	Start Rec.	End Rec.	Start Shot	End Shot	Start Time	End Time	Jul. Day
1	f321001140.segy	1	91	(1)	(1)	00:11:52	00:26:52	321
1	f321002719.segy	1	49	(1)	(1)	00:27:32	00:35:17	321
1	f321004149.segy	1	1753	(1)	(1)	00:42:02	04:41:04	321
1t	•	1755	1879	(1)	(1)	04:41:19	04:56:49	321
2	•	1881	2632	941	1316	04:57:04	06:30:04	321
2t	•	2625	2768	1313	1384	06:30:19	06:47:49	321
3	•	2769	3456	1385	1728	06:48:04	08:13:04	321
3t	•	3449	3688	1725	1844	08:13:19	08:42:49	321
4	•	3689	4049	1845	2025	08:43:04	09:28:04	321
5	95321181526.segy	107	1650	54	825	19:43:14	22:55:12	321
7	95322063241.segy	1	795	(1)	(1)	06:32:57	08:12:12	322
7t	•	797	1145	(1)	(1)	08:12:27	08:55:57	322
8	•	1147	1818	574	909	08:56:12	10:19:12	322
8t	•	1811	2002	906	1001	10:19:27	10:42:57	322
9	•	2003	2410	1002	1205	10:43:12	11:33:12	322
10	95322125135.segy	133	686	67	343	13:08:12	14:17:12	322
11	95322142137.segy	45	228	23	114	14:27:12	14:49:12	322
12	•	221	596	111	298	14:49:27	15:35:12	322
13	•	845	1420	423	710	16:07:12	17:18:12	322
14	•	1413	1868	707	934	17:18:27	18:14:12	322
15	•	1861	2012	931	1006	18:14:27	18:32:12	322
V994d	95322193033.segy	1	916	1	458	19:30:33	21:24:10	322
16	95323010106.segy	25	1032	13	516	01:04:10	03:09:10	323
16t	•	1025	1056	513	528	03:09:25	03:12:55	323
17	•	1057	2832	529	1416	03:13:10	06:54:10	323
18	•	2825	4792	1413	2396	06:54:25	10:59:10	323
19	•	4785	4960	2393	2480	10:59:25	11:20:10	323
20	95323222937.segy	1	1390	1	695	22:29:50	01:23:50	323
21	95324012817.segy	1	974	1	487	01:28:20	03:29:05	324
23	•	967	3988	484	1994	03:29:20	09:46:06	324
24	•	3983	5204	1992	2602	09:46:21	12:20:06	324
obs1a	95331195845.segy	155	2136	78	1068	20:18:38	00:34:01	331
obs1b	•	2137	3393	1069	1697	00:34:16	03:16:15	332
obs1c	•	3395	5190	1698	2595	03:16:30	09:07:07	332
obs2a	95332184612.segy	1	1766	1	883	18:46:23	22:33:44	332
obs2b	95333012105.segy	23	1860	12	930	01:24:02	05:20:04	333
25	95333094608.segy	1	1022	1	511	09:46:19	11:57:06	333
26	•	1015	1208	508	604	11:57:21	12:21:35	333
27	•	1201	1758	601	879	12:21:51	13:32:00	333
28	•	1751	2518	876	1259	13:32:16	15:10:01	333
V995b	95333184804.segy	1	1214	1	607	18:48:16	21:24:03	333
29	95334191718.segy	17	688	9	344	19:19:04	20:42:04	334
30	•	681	1216	341	608	20:42:19	21:48:04	334
31	•	1209	1512	605	756	21:48:19	22:25:04	334
31t	•	1529	1756	765	878	22:35:34	23:03:49	334
32	•	1757	2840	879	1420	23:04:04	01:19:19	334

(1) shots have to be re-numbered

Table 6: SCS lines, navigation.

Line #	start latitude	start longitude	end latitude	end longitude	number of shots	length of line (km)	avg. shot dist. (m)
Leg 1							
1	31° 57.1869	-75° 19.1965	31° 45.7115	-75° 34.7098	(1)	32.36	(1)
1t	31° 45.6997	-75° 34.7224	31° 44.6920	-75° 34.2502	(1)	2.01	(1)
2	31° 44.7011	-75° 34.2256	31° 48.4241	-75° 28.9626	376	10.78	28.75
2t	31° 48.4310	-75° 29.0301	31° 47.5135	-75° 28.6915	72	2.06 (2)	28.75 (2)
3	31° 47.5046	-75° 28.7045	31° 43.7729	-75° 33.5334	344	10.28	29.97
3t	31° 43.8092	-75° 33.4896	31° 43.2226	-75° 32.5185	120	3.58 (2)	29.97 (2)
4	31° 43.2418	-75° 32.5063	31° 45.3265	-75° 29.7690	181	5.79	32.17
5	31° 54.1982	-75° 37.2823	31° 43.9358	-75° 27.0843	772	24.88	32.27
7	31° 46.1331	-75° 36.4169	31° 50.2210	-75° 30.5995	(1)	11.88	(1)
7t	31° 50.2176	-75° 30.5960	31° 50.3553	-75° 27.4706	(1)	4.93	(1)
8	31° 50.3806	-75° 27.4524	31° 49.6480	-75° 24.2401	336	5.23	15.61
8t	31° 49.6546	-75° 24.2688	31° 50.1484	-75° 24.0855	96	1.48 (2)	15.61 (2)
9	31° 50.1546	-75° 24.0874	31° 50.5651	-75° 25.7621	204	2.74	13.50
10	31° 49.3387	-75° 26.4103	31° 51.2023	-75° 25.9037	277	3.54	12.83
11	31° 51.4240	-75° 26.6154	31° 50.8915	-75° 27.1637	114	1.31	14.40
12	31° 50.8992	-75° 27.1879	31° 50.5566	-75° 25.7078	188	2.41	12.89
13	31° 51.0928	-75° 24.5803	31° 49.0567	-75° 25.1282	288	3.87	17.05
14	31° 49.0802	-75° 25.1214	31° 46.7346	-75° 27.9026	228	6.17	27.18
15	31° 46.7489	-75° 27.8545	31° 47.6190	-75° 28.6864	76	2.08	27.73
v994d	31° 48.7903	-75° 28.4154	31° 45.5173	-75° 36.8080	458	14.54	31.82
16	31° 47.0077	-75° 34.4840	31° 39.2942	-75° 28.2910	504	17.30	34.39
16t	31° 39.3488	-75° 28.2893	31° 39.2067	-75° 28.5025	16	0.52 (2)	34.39 (2)
17	31° 39.2137	-75° 28.5242	31° 45.0642	-75° 47.0783	888	31.18	35.15
18	31° 45.0192	-75° 47.0538	32° 00.0212	-75° 35.9358	384	32.83	33.40
19	31° 59.9972	-75° 35.9913	31° 58.3820	-75° 35.5437	88	3.07	35.29
20	32° 24.7738	-76° 07.8160	32° 34.0162	-76° 15.1555	695	20.60	29.68 (3)
21	32° 33.8030	-76° 15.3928	32° 26.0155	-76° 16.9905	487	14.62	30.08 (3)
23	32° 41.7966	-76° 17.0783	32° 41.8236	-75° 55.4058	1511	44.41	29.41 (3)
24	32° 41.7966	-75° 55.4129	32° 52.0658	-75° 55.09 16	611	19.03	31.18 (3)
Leg2							
obs1a	30° 54.4883	-75° 55.0589	30° 58.4136	-75° 32.8674	991	31.34	31.66
obs1b	30° 58.4183	-75° 32.8484	31° 03.8007	-75° 43.6765	629	19.87	31.64
obs1c	31° 03.8030	-75° 43.6948	30° 49.0062	-75° 39.5587	898	28.18	31.42
obs2a	31° 44.1064	-75° 40.3594	31° 50.3169	-75° 24.7987	883	27.06	30.68
obs2b	31° 54.0587	-75° 36.4428	31° 40.1180	-75° 29.0473	919	28.20	30.72
25	31° 45.6084	-75° 32.7726	31° 45.9374	-75° 27.1014	511	8.95	17.55
26	31° 45.9001	-75° 27.1450	31° 46.7804	-75° 27.8041	97	1.93	20.10
27	31° 46.8051	-75° 27.7662	31° 43.9824	-75° 31.6553	279	8.05	28.96
28	31° 43.9832	-75° 31.6072	31° 50.1903	-75° 30.6401	284	11.60	30.29
v995b	31° 50.4030	-75° 25.0075	31° 46.5864	-75° 35.9330	607	18.59	30.67
29	31° 47.7746	-75° 35.3745	31° 51.1142	-75° 31.1656	336	9.06	27.04
30	31° 51.1007	-75° 31.2080	31° 47.4252	-75° 28.6687	268	7.89	29.55
31	31° 47.4556	-75° 28.7056	31° 48.9480	-75° 26.8850	152	3.98	26.36
31t	31° 49.3203	-75° 26.3473	31° 50.3801	-75° 27.4721	114	2.64	23.36
32	31° 50.3494	-75° 27.4827	31° 54.3181	-75° 37.3880	542	17.19	31.77

(1) line has to be extracted from field data again.
(2) based on shot spacing from previous line and number of shots, not distance between coordinates (turn).
(3) header entries for navigation not correct.

Total length of profiles: 560 km.
Note that lines were split such that there is an overlap of a few shots at the beginning/end of line.

Table 7: Naming conventions for split lines in data archive.

Line #	Naming convention
1-24	linexx.segy (1)
25-32	line_xx.segy (1)
obs1a-2b	line_xx.segy (1)
v994d	lineAA_994D_VSP2.segy
v995b	line_V995b01.segy

(1) xx: line no. (obs1a etc. for OBS lines).

Table 8: Header entries related to navigation/shot numbering in split lines.

	bytes in trace header	SEISUNIX header keyword	PROMAX header keyword
record number	1-4	tracl	(used internally)
record number	5-8	tracr	TRACENO
shot number	9-12	fldr	FFID
shot number	17-20	ep	SOURCE
latitude (degree) (1)	141-142	afilf	AAXFILTz
latitude (whole minute) (1,2)	143-144	afils	AAXSLOPz
latitude (1/1000 minute) (1,2)	145-146	nofilf	FREQXNz
longitude (degree) (1)	147-148	nofils	FXNSLOPz
longitude (whole minute) (1,2)	149-150	lcf	FREQXLz
longitude (1/1000 minute) (1,2)	151-152	hcf	FREQXHz

(1) Interpolated PCODE antenna positions.
(2) I.e., floating point value xx.yyyy: xx in bytes 143-144/149-150, yyyy in bytes 145-146/151-152.
Note that the header entries for positions are not according to the SEG-Y standard and might be lost during processing.

Table 8: Airgun distance from GPS antennas, stern of ship.

	x (m) (1)	y (m) (2)
WHOI GPS-antenna to airgun	51.89	-6.02
USGS GPS-antenna to airgun	64.54	2.43
stern of ship to airgun	45.26	-

(1) distance parallel to ship track, positive is behind ship.
(2) distance perpendicular to ship track, positive if antenna on port side relative to streamer/airgun.

Table 9: Technical data of *Teledyne* streamer.

number of channels (active sections)	2
length of 1 active section	50 m
number of phones per channel	49
length of dead section between channels	25 m
distance stern of ship/beginning 1st active section	94 m

Figure Captions

Fig. 1: Principle operation of a GI gun. From the GI gun's operational manual.

Fig. 2: Tracks of single channel seismic data acquired during both legs in the Blake Ridge region.

Fig. 3: Tracks of single channel seismic data acquired during Leg 1 in the Blake Ridge region.

Fig. 4: Tracks of single channel seismic data acquired during Leg 1 over the Blake Ridge diapir.

Fig. 5: Tracks of single channel seismic data acquired during Leg 2 in the Blake Ridge region.

Fig. 6: SCS line 1, the dip line over ODP Leg 164 Sites 994 and 995. Stacked section without amplitude manipulation.. Trace numbering is arbitrary, distance between neighboring traces about 30 m.

Fig. 7: SCS line 23 over the Blake Ridge diapir. Migration with water velocity. AGC window 1 s. Trace numbering is arbitrary, the average distance between neighboring traces 29.41m.

Fig. 8: Navigation for OBS experiment 1. Deployment positions are marked by filled circles, recovery positions by open circle.

Fig. 9: Navigation for OBS experiment 2 and the walkaway experiments. Deployment positions of OBSs are marked by filled circles, recovery positions by open circles. Triangles mark waypoints for VSP experiments (V994/V994': VSP over Site 994D, V995/V995': VSP over Site 995B). Dashed lines are tracks of SCS lines 1 (see also fig. 6) and v995b.

Fig. 10: Vertical component (channel 1) at OBS a3 deployment 2, line obs 2a (ref. fig. 9). The line was shot from the southwest to the northeast. Reduction is velocity 3 km/s. Trace numbering is arbitrary. Average spacing between neighboring shots is 30.68 m.

Fig. 11: Sketch of the geometry of the walkaway VSP experiment over Site 995B.

Fig. 12: Part of line V994D02, vertical component (channel 4). The line was shot from the northeast to the southwest. Trace numbering is arbitrary. Average shot spacing is 31.82 m. Receiver depth was 649.9 mbsf.

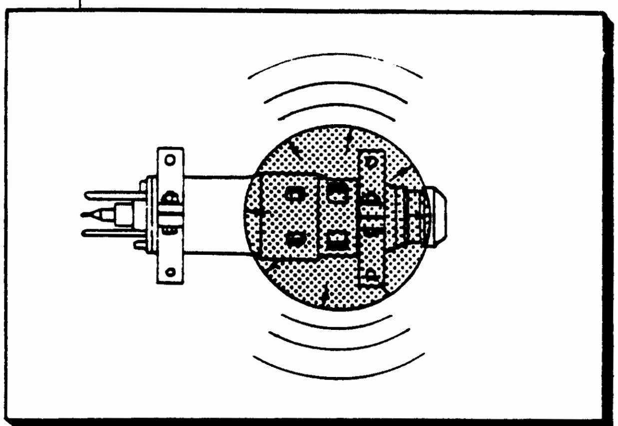
Fig. 13: Part of line V995B08, vertical component (channel 4). The line was shot from the southwest to the northeast. Trace numbering is arbitrary. Spacing between shots is approximately 30 m. Receiver depth was 175.8 mbsf.

Fig. 14: Line V995B08, vertical component (channel 4). The line was shot from the southwest to the northeast. Trace numbering is arbitrary. Spacing between shots is approximately 30 m. Receiver depth was 175.8 mbsf.

#95025771

Fig. 1

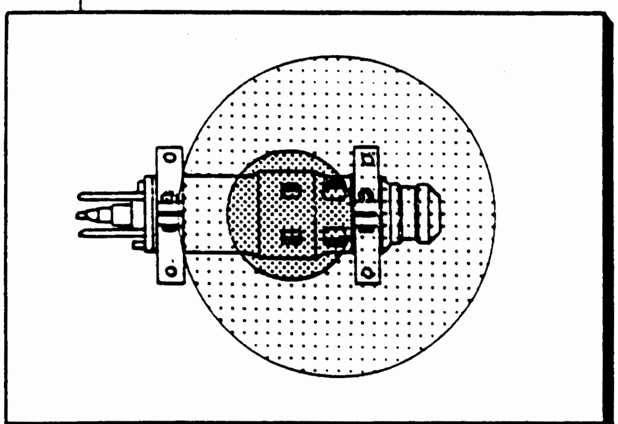
HOW IT WORKS



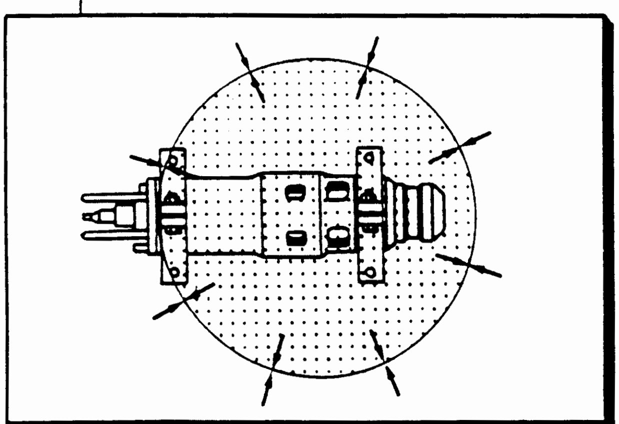
(1) **GENERATOR "G"** is fired

PULSE IS EMITTED

and the bubble starts to expand...



(2) When the bubble approaches its maximum size, **INJECTOR "I"** is actuated, injecting air within the bubble.



(3) The injected volume of air REDUCES and RESHAPES the bubble oscillation.

US Patent N° 4,735,281 and others pending

Fig. 2

CH18_95 Single Channel Seismics

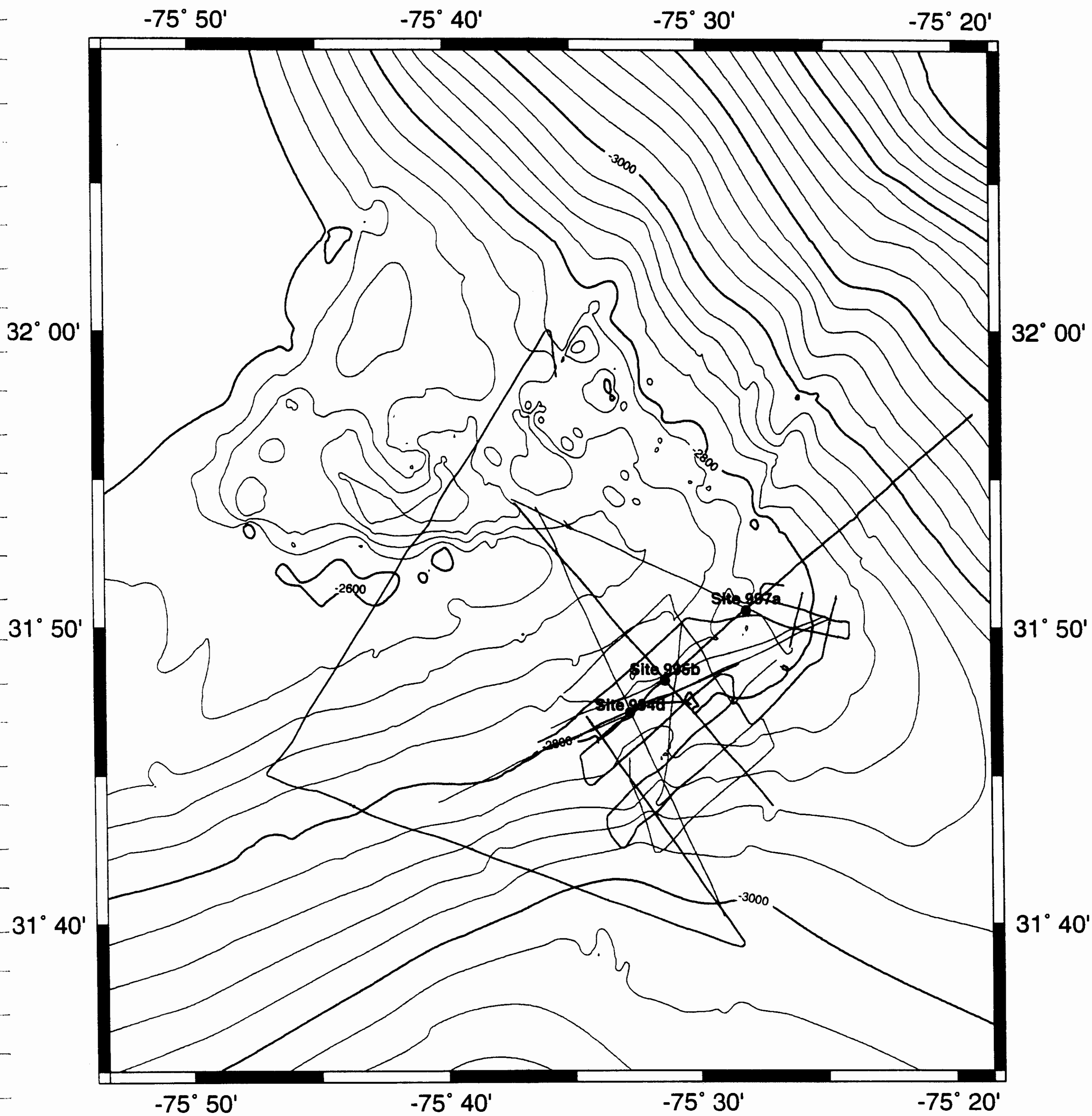
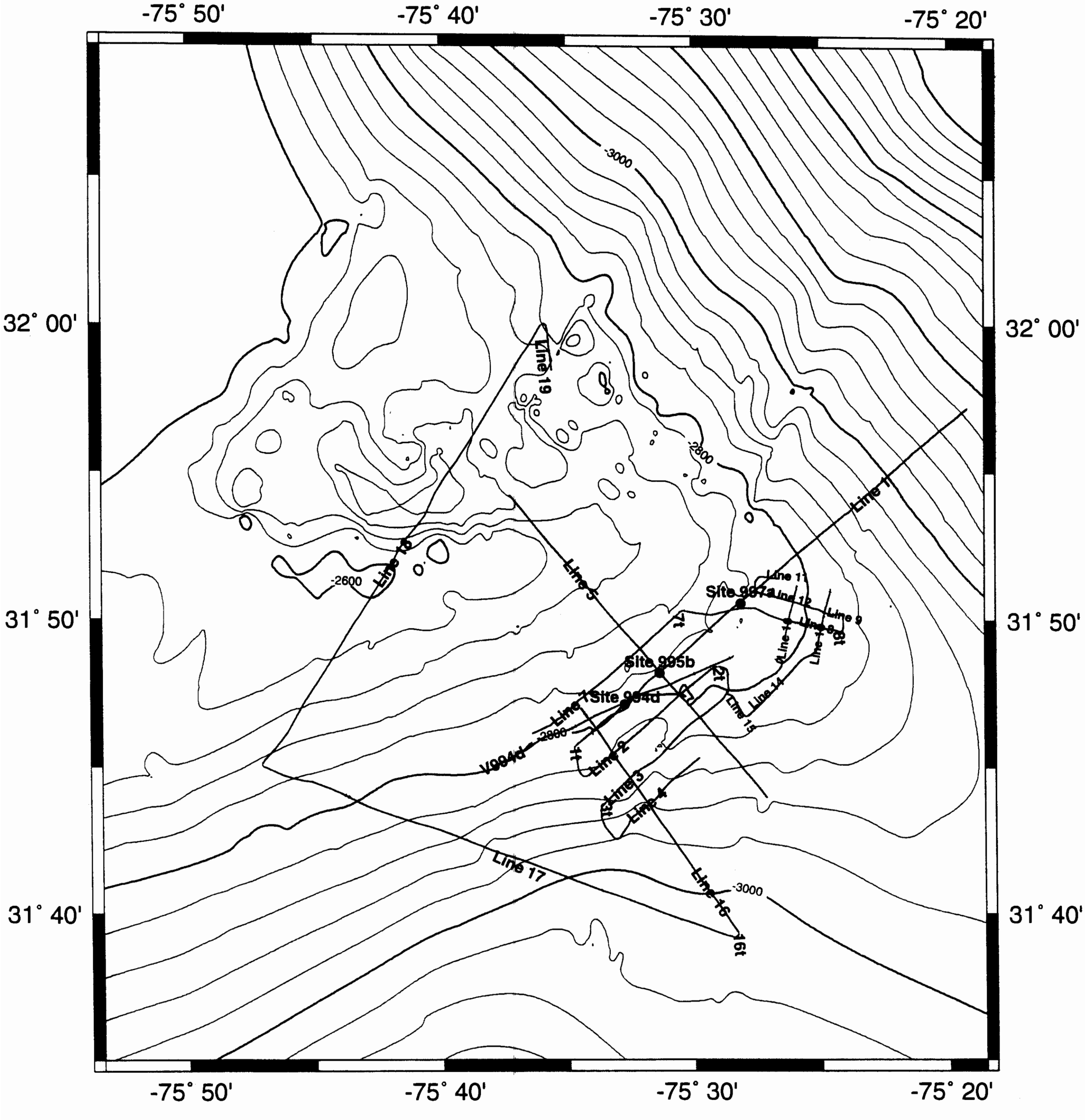


Fig. 3

Single Channel Seismics Leg1, Blake Ridge



Single Channel Seismics Leg 1, Blake Ridge Diapir

Fig. 4

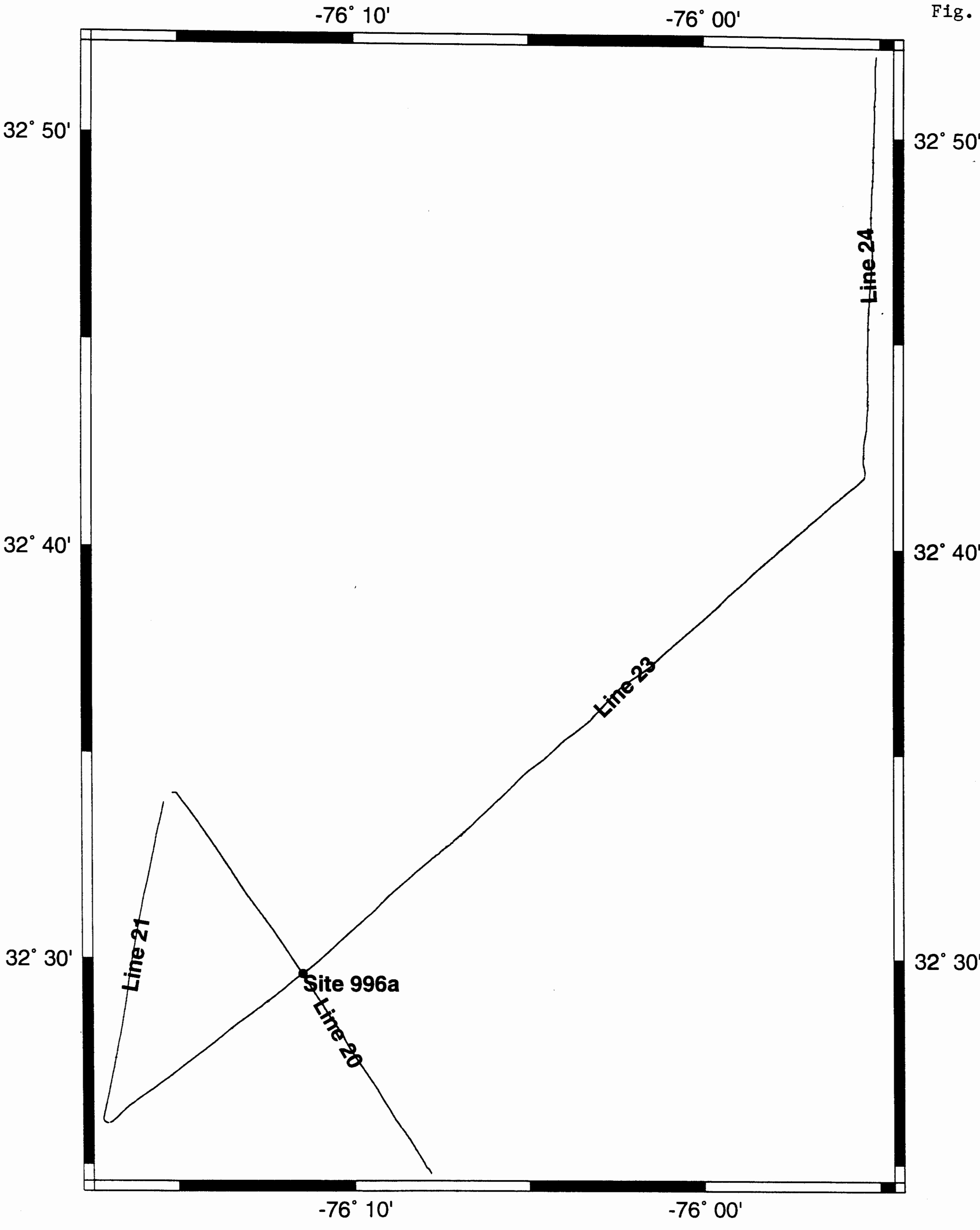
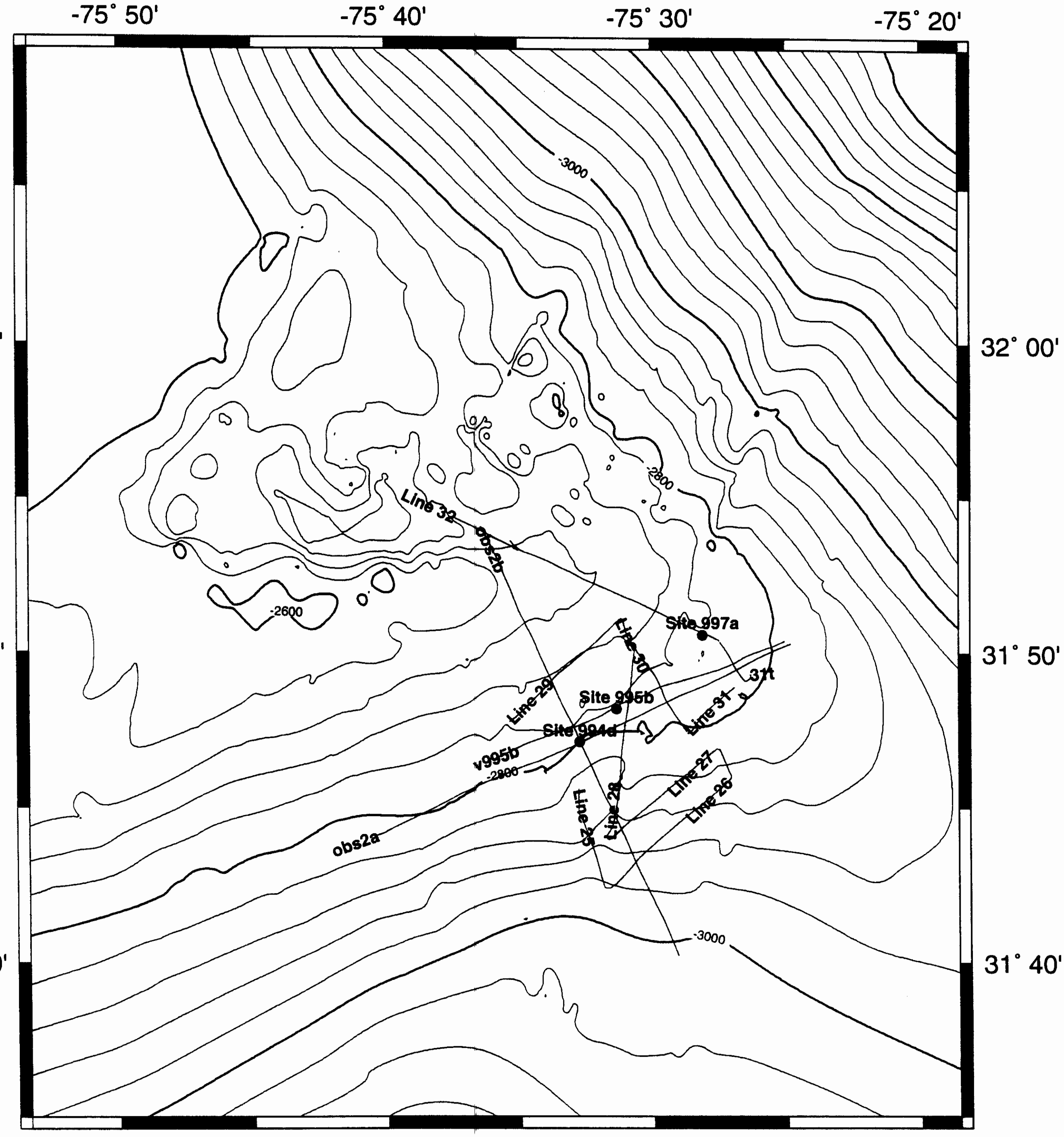
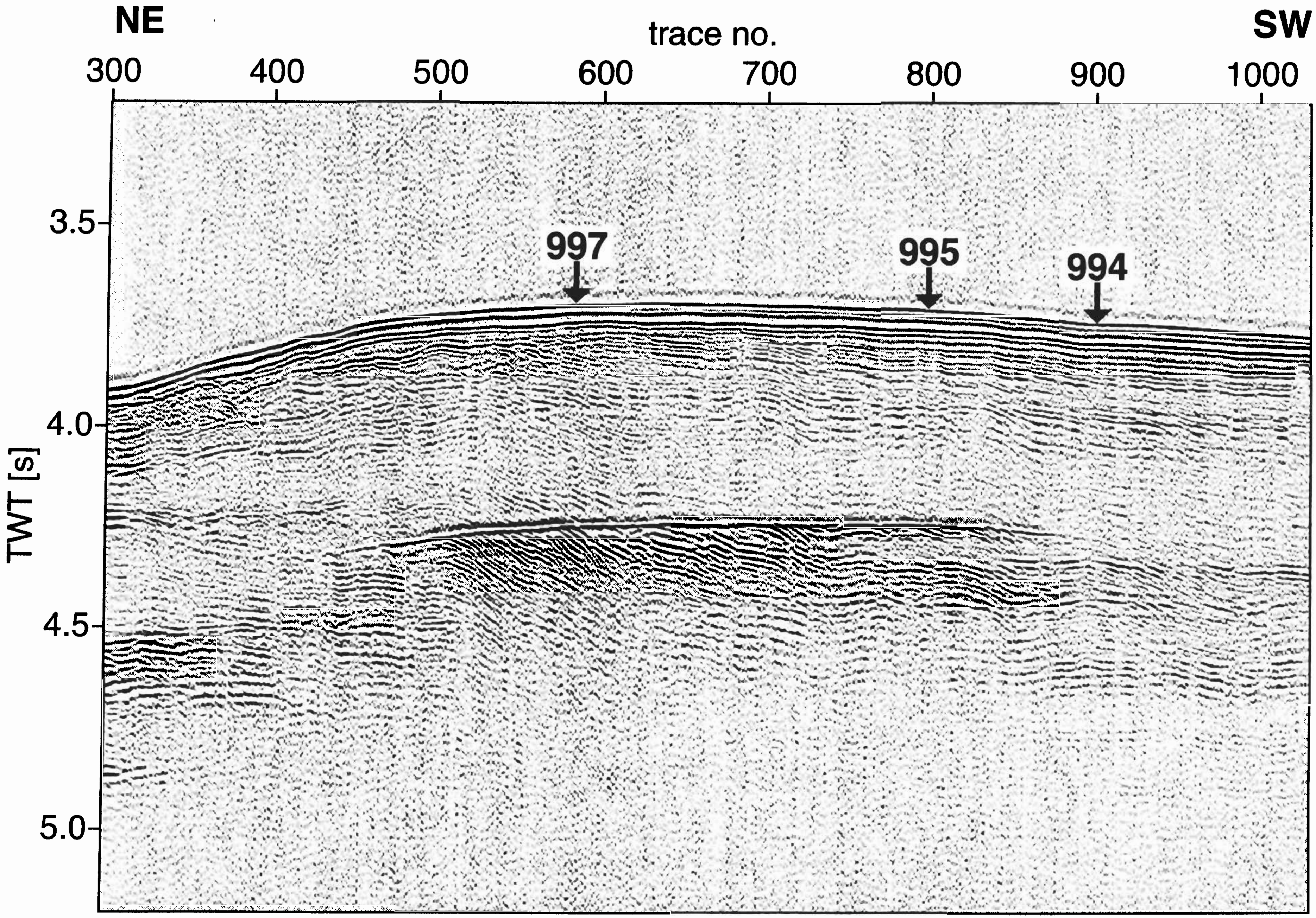


Fig. 5

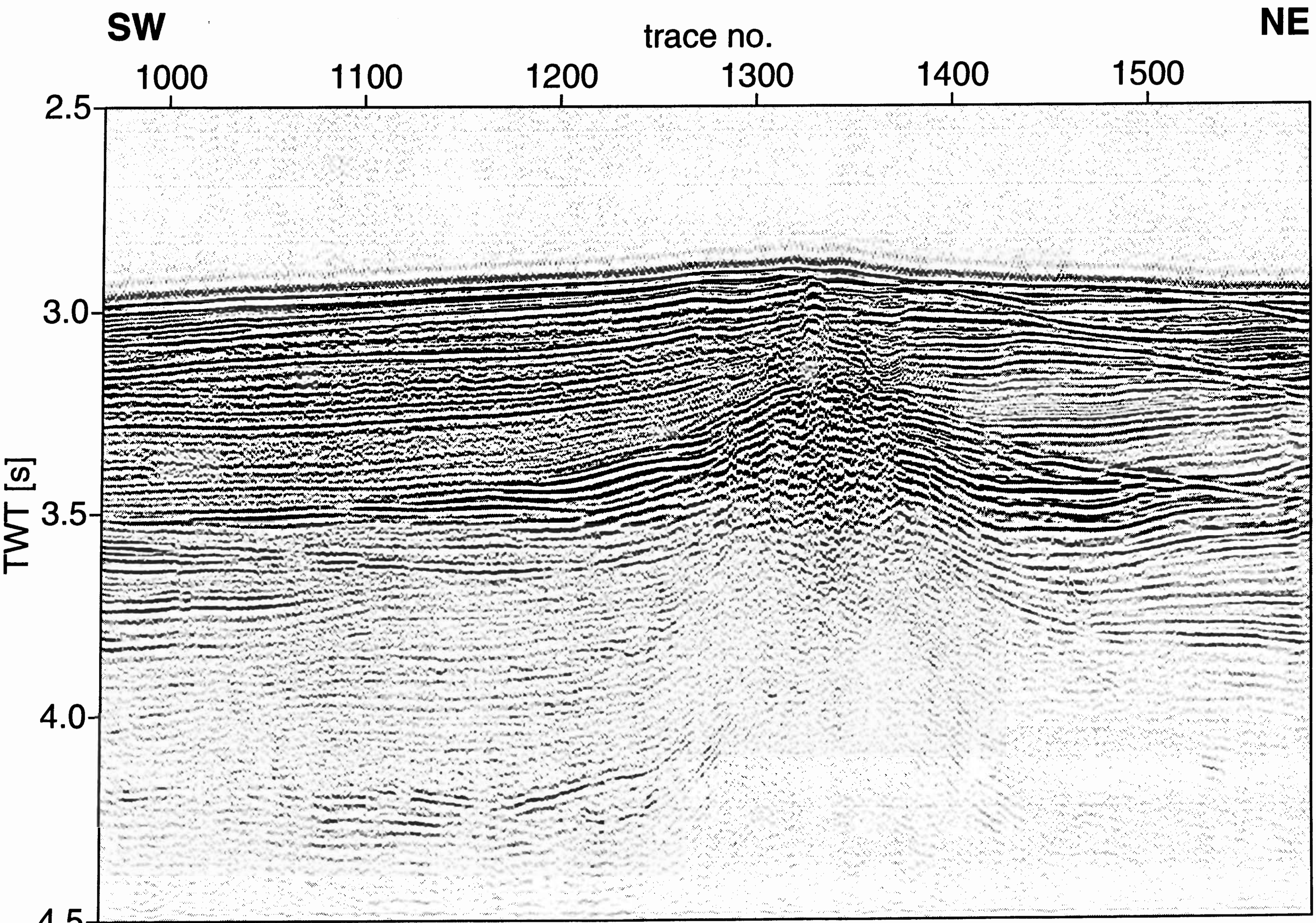
Single Channel Seismics Leg2





line 1 stacked

Fig. 7



line 23 migrated (water velocity)

Fig. 8

OBS Deployment 1

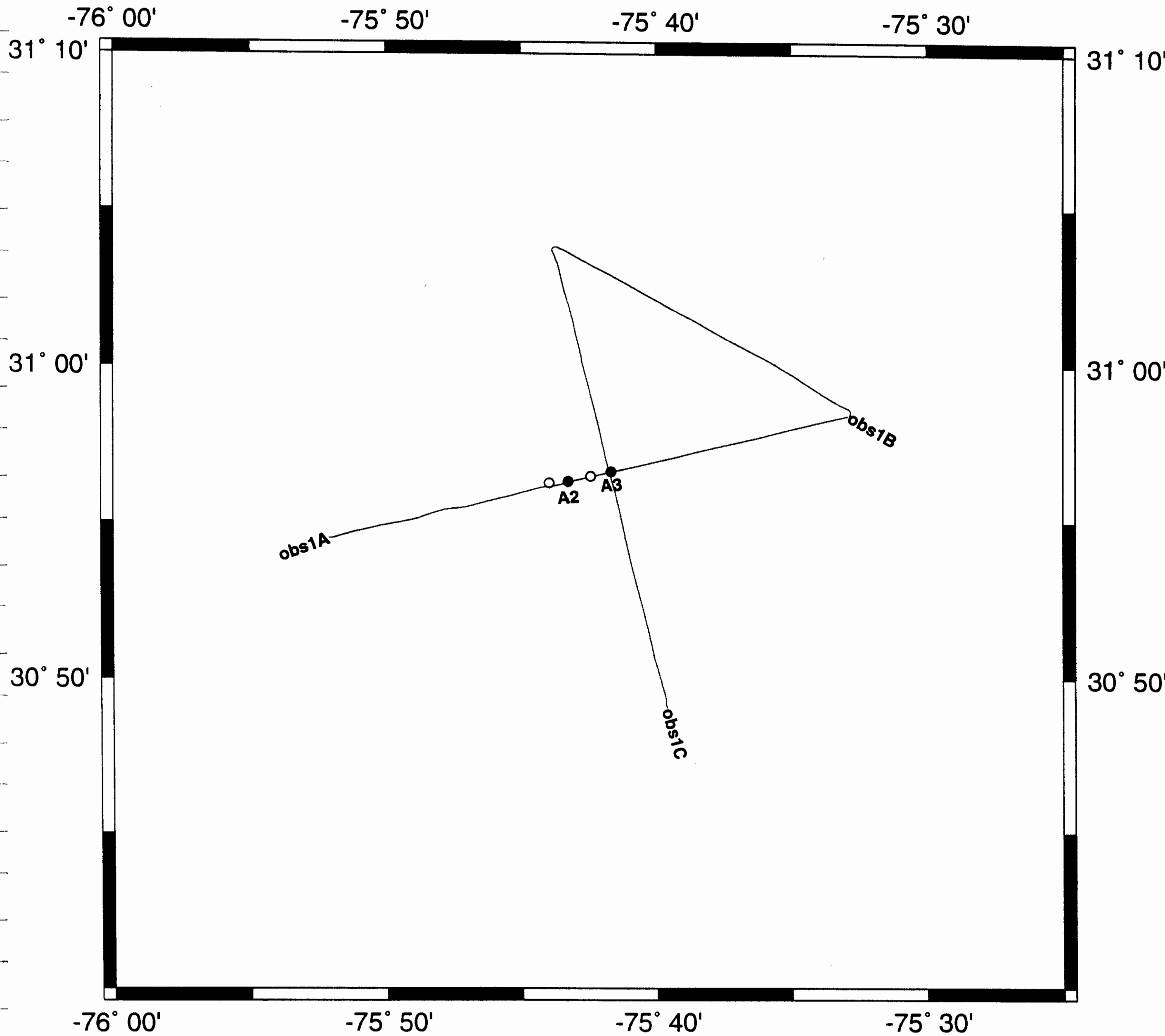


Fig. 9

OBS Deployment 2

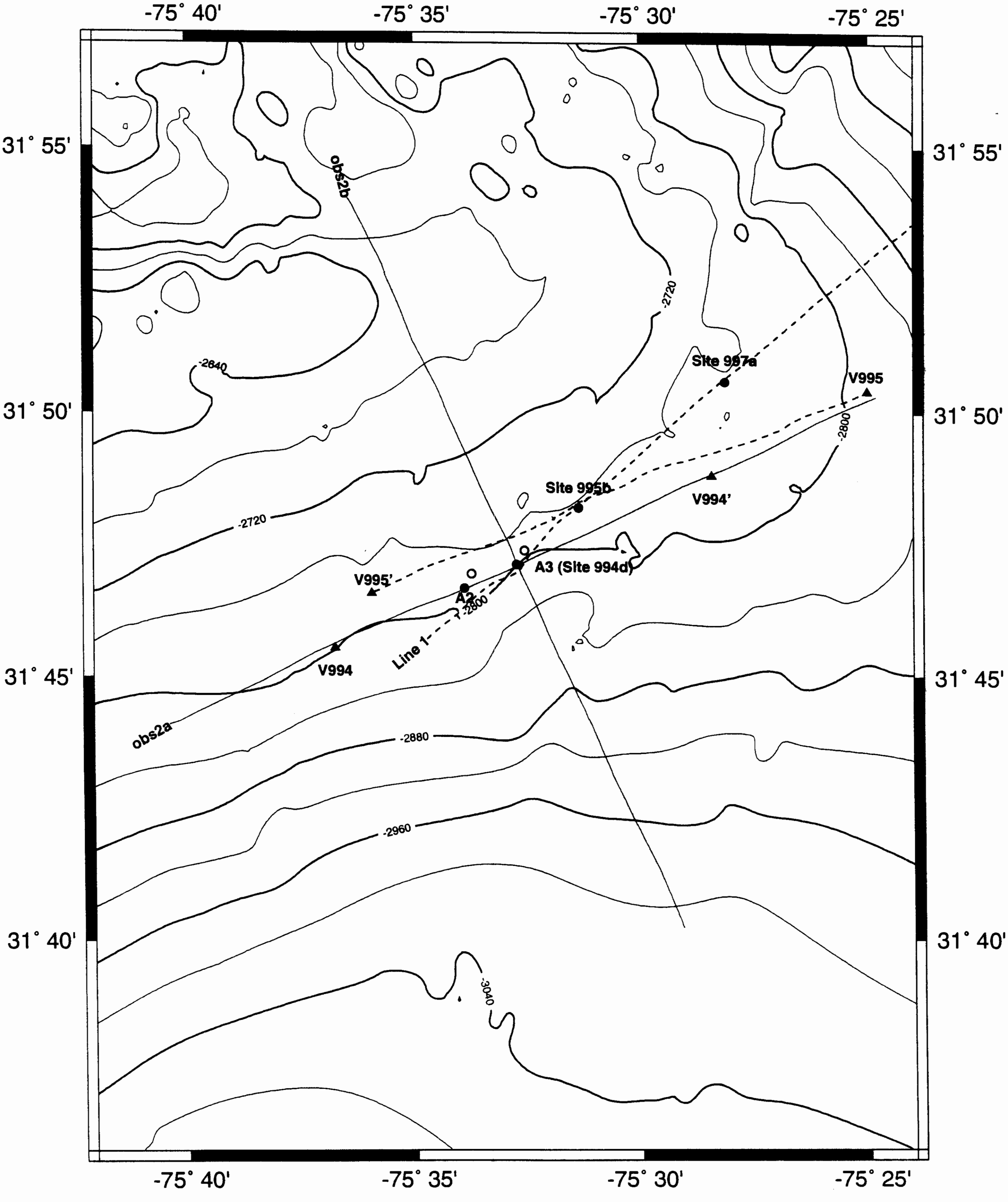
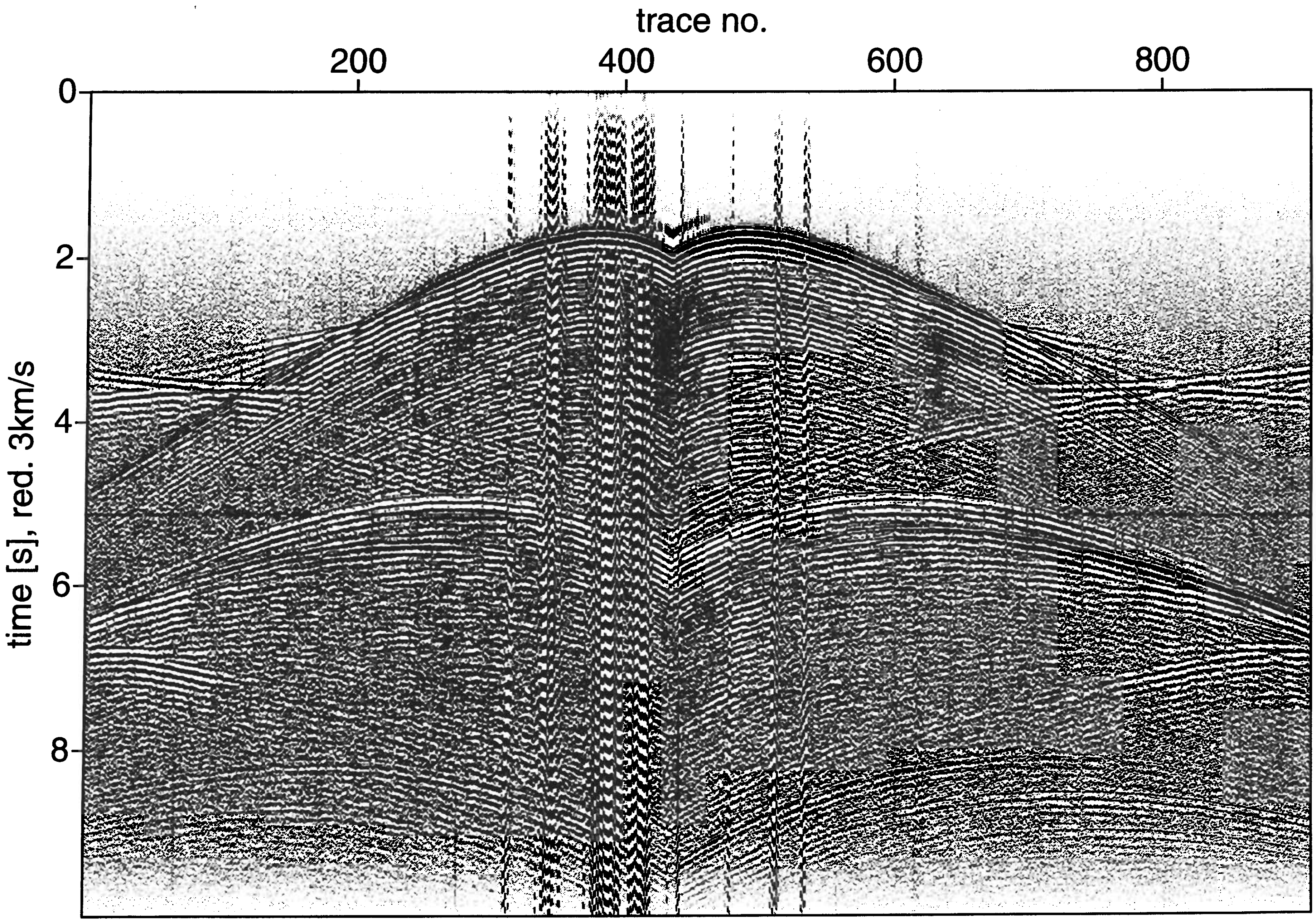
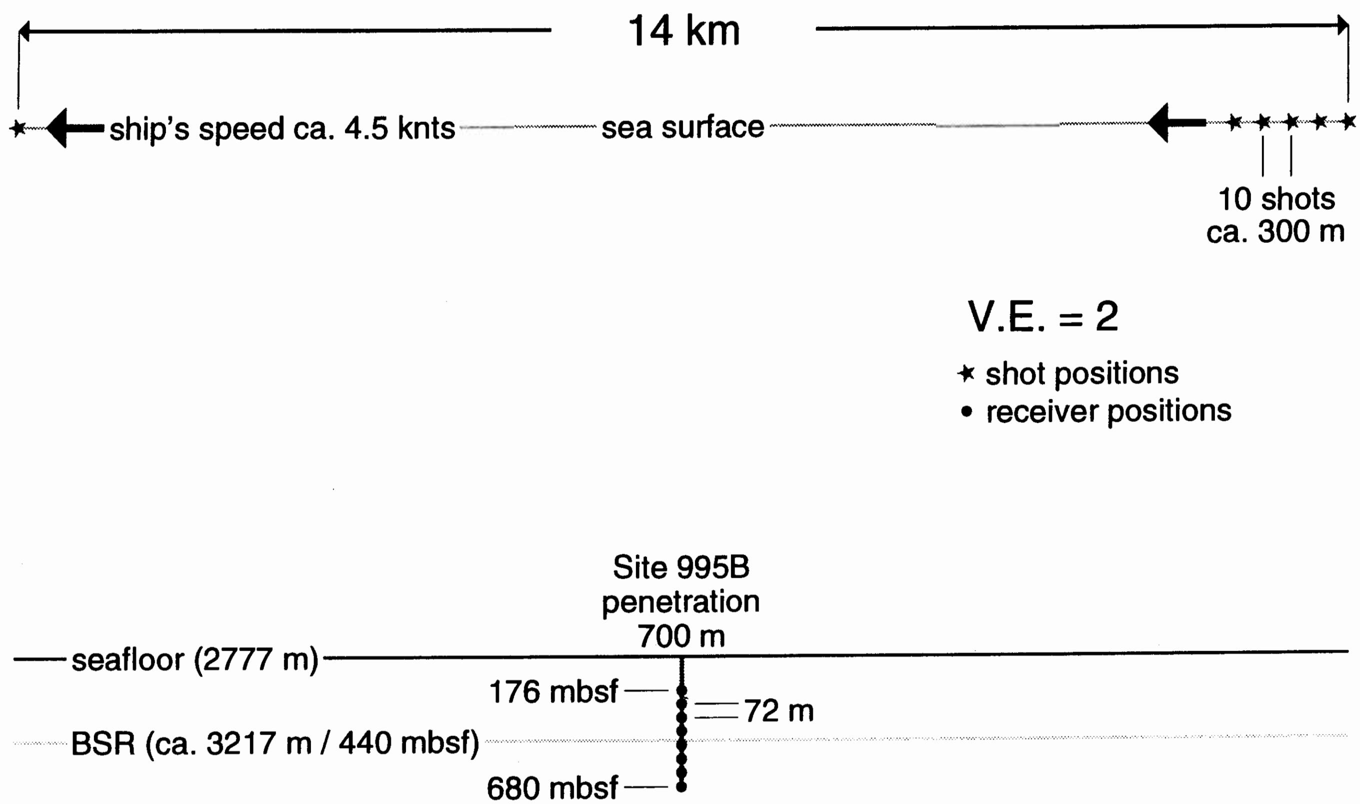


Fig. 10



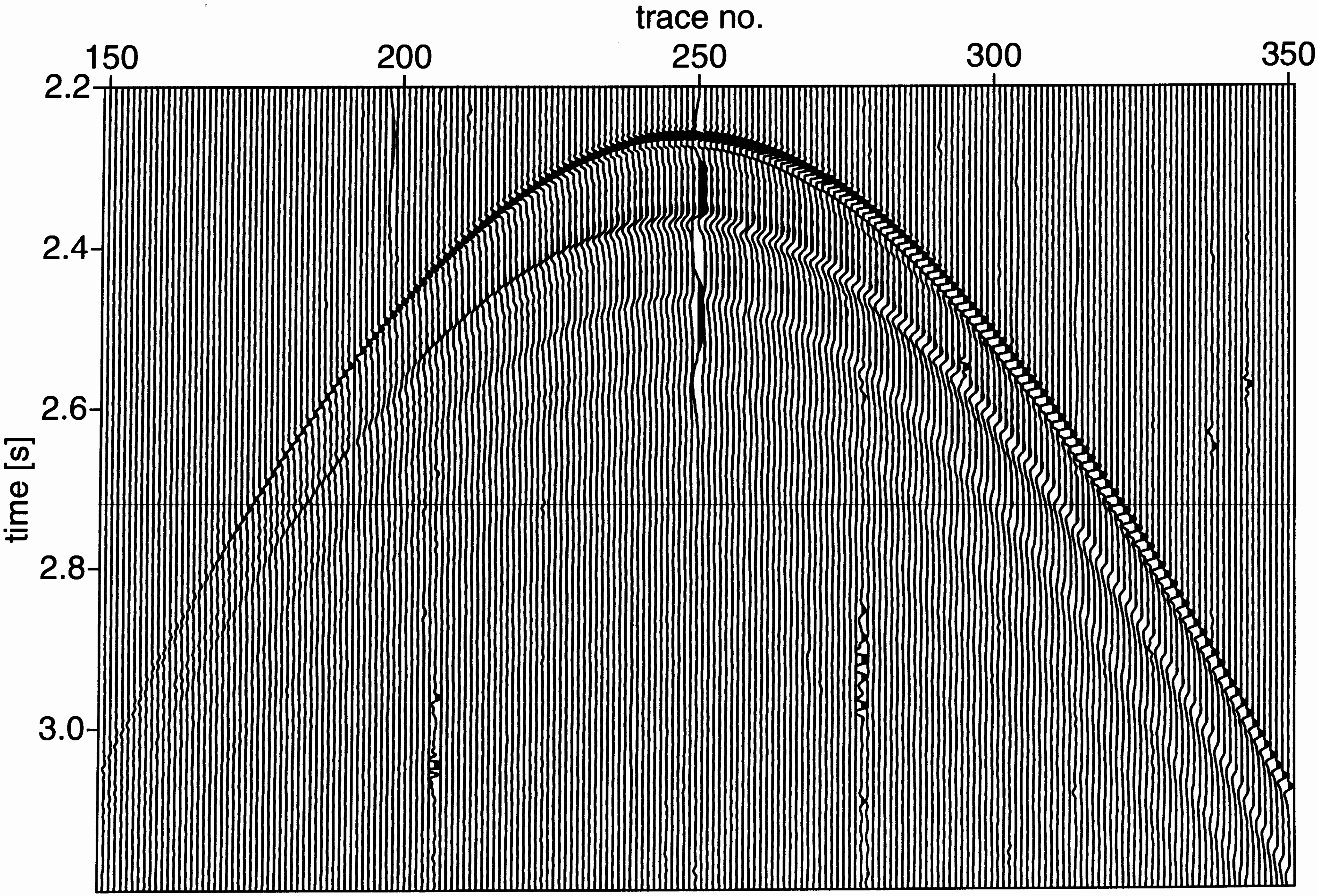
Site 994 OBS a3 channel 1, tpow=2

Fig. 11



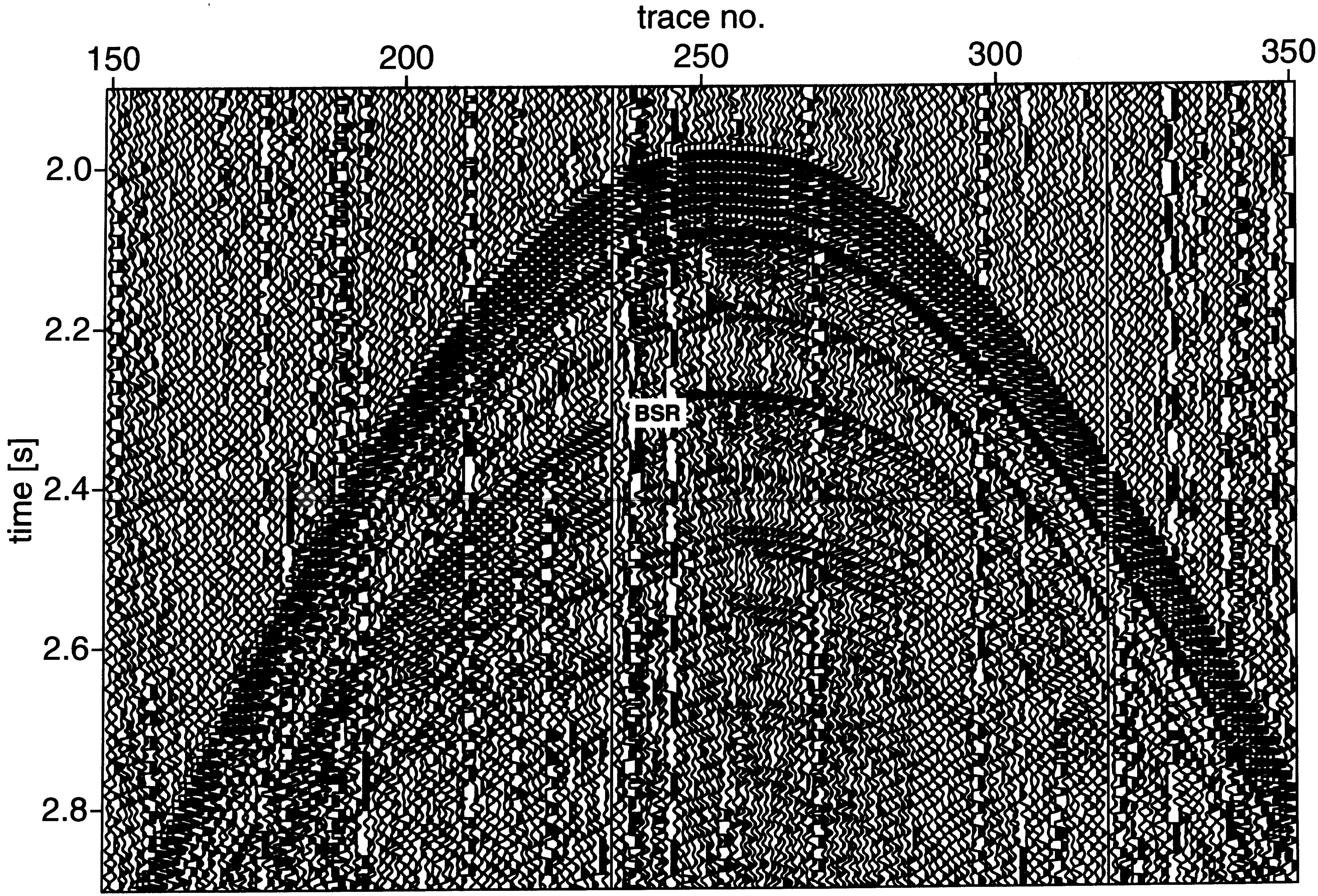
walkaway VSP geometry

Fig. 12



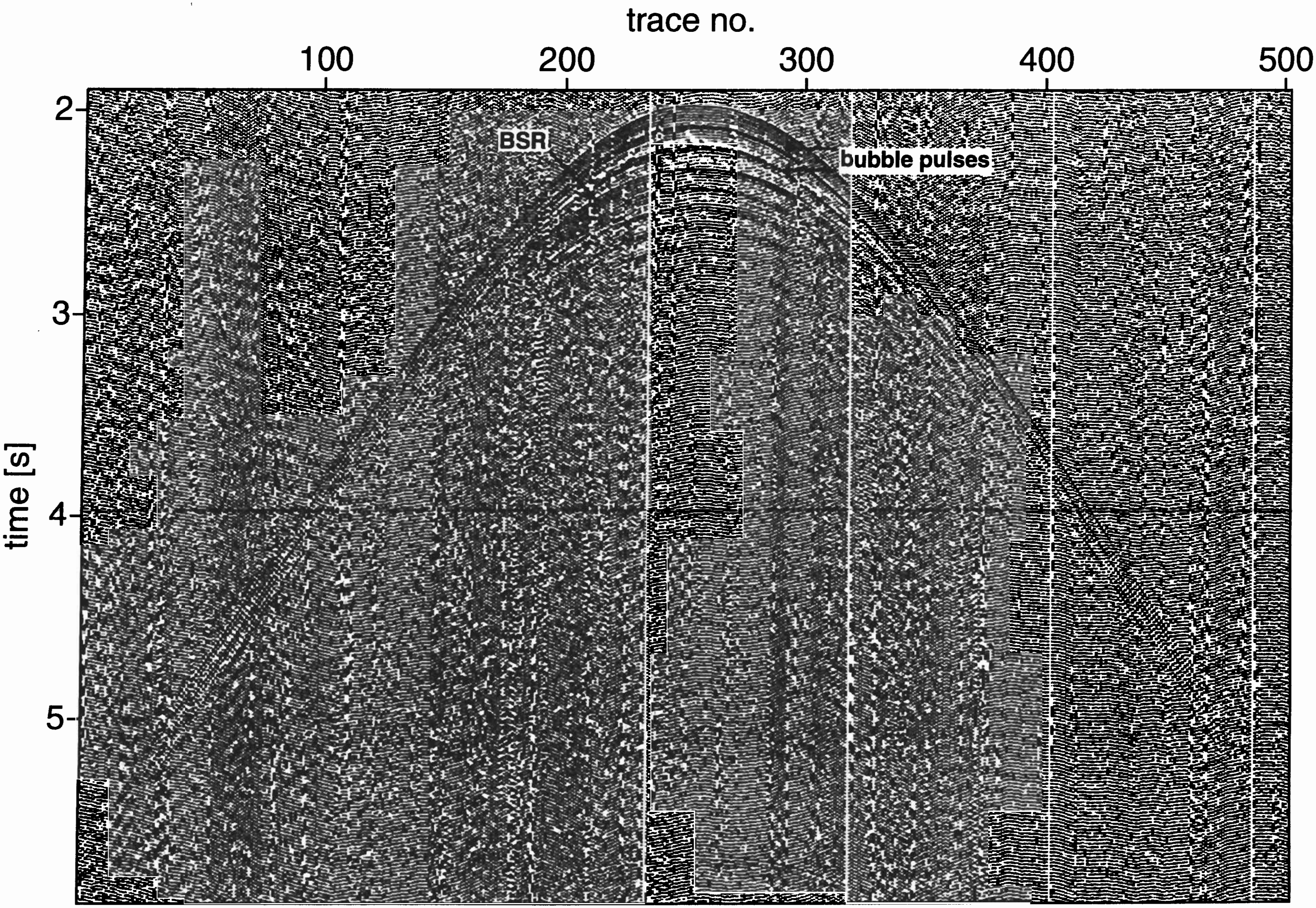
Site 994D 3460m ch 4

Fig. 13



Site 995B VSP 2964m ch4

Fig. 14



Site 995B VSP 2964m ch4 tpow=1